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Mine Clearance in a Virtual Environment

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Abstract

At the same moment as France completed destruction of its stock of anti-personnel mines (21/12/99) in accordance with the 1998 Ottawa Agreement, in more than 60 countries there were 100 million live, buried "permanent sentinel" mines continuing to mutilate the inhabitants of mine-infested regions, most of the wounded being children (600,000 people affected over 20 years, one person killed every 20 minutes by these devices designed to terrorise civil populations during the war, whose effects persist for a long time afterwards). Paradoxically, confronted by the sophisticated manufacturing techniques of these "cowardly weapons", French sappers use a rudimentary mine clearance technique to render zones viable for the civil population. With the aid of a bayonet-type tool, the operator probes the ground until he hits a suspect device. This task is carried out blind and one of the problems is identifying the presence of a mine and distinguishing it from a false alarm. This technique, demanding 100% results, based on the skill and experience of the mine disposal team, is taught by the Minex Centre of the Applied Engineering Applications College.

The Human Factors division of ETAS (Etablissement Technique d'Angers), a part of the DGA, has built and tested version 1 of a demonstrator and virtual environment for teaching this technique. One group under training now has been able to distinguish the methods for discriminating shapes after several contacts of the probe with the mine.

In its version 2 (addition of force feedback), this demonstrator has become a genuine teaching tool for mine clearance strategy, enabling the instructor to validate the relevance of the students' probing, to minimise the amount of probing and therefore to increase the reliability of the decisions during an actual operation. In due course, this tool will also enable the technique to be taught to civilian populations and thus accelerate the process of decontamination which still takes a long time, costs a lot of money and, especially, costs lives.

Technology development is already enabling us to consider version 3, a portable system which uses mathematical analysis of the probing geometry during real operations, and by comparison with a database, offers genuinely enhanced assistance to making decisions and taking action.

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1. Problems of Mine Clearance

The difficulty of mine clearance is that of DRI (detection, recognition, identification) associated with some action.

The main problem is detecting the device: the mine clearance expert probes the ground in a systematic manner in a 5×3 triangular grid arrangement to try and *detect* the presence of a foreign body. If the probe hits something, the mine clearance expert halts his movement. He then probes in order to discover the extent of the object and to determine its shape, which will enable him to *recognise* the presence of an object. He then clears away the soil covering the object and *identifies* it as being a mine or not, a munition or some unknown device.

If a device is present, a specialist intervenes who, after having made a detailed identification, detects any booby traps, analyses the condition and mode of triggering, and decides to deal with the device either by destruction or by rendering safe.

This paper is only concerned with the DRI task in the initial phase; it is a difficult task, performed blind, necessitating the mobilisation of sensors in seeking stimuli which are indicators both for the accomplishment of the task and for a perfectly controlled motor activity; indeed the relevance of the indicators is dependent on the steadiness of the prodding (the angle of incidence of the probe must remain constant), this angle is a safety factor and makes it possible to attack the mine at its edges and not from above where the initiator is generally situated. (angle of incidence lies between 30 and 35°).

2. Aim of the Research

In order to design a simulator for teaching manual probing specific to the activities involved in mine clearance, the Human Factors division of ETAS, in association with the Angers Cognitive Psychology Research Laboratory, engaged in research into learning conditions in a virtual environment. This research was the subject of a thesis entitled: *Influence of sensorial methods and individual characteristics on the conduct of target detection in compared environments: the case of virtual and actual environments.*

The conduct of sensorial learning was observed for a task in a real environment and then in a virtual environment. The experiments were conducted in real

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time and took three aspects into account: the detection of shapes; the detection of textures; and the detection of sounds. Detection was based on visual, kinaesthetic and auditory indicators. The experiments conducted in a virtual environment were limited to a shape-detection task.

Nowadays, virtual reality based on visual immersion makes it possible to explore and augment visual information in an enhanced manner and it also allows, at a lower level, transmission of multi-modal sensorial information by haptic, tactile or auditory feedback systems, close to those felt in real life.

For qualitative and financial reasons, this thesis was restricted to a part of the significant information of a blind, sensori-motor task. The mine clearance expert's task was not reproduced identically. A selection was made of the sensorial modalities of exploration. Emphasis was placed on the guiding of movements aiming at the target using visual and auditory indicators excluding any use of a haptic interface. Therefore the strategy of probe movement was tested in virtual space:

1. by observing and analysing a shape detection task;
2. by comparing the learning of this task when conducted in a real and in a virtual environment.

3. Development of Virtual Reality and Research in a Multi-disciplinary Team

The number of articles concerning new virtual reality interfaces shows the diversity of applications and their development from the leisure domain into the professional world and firmly establishes virtual reality as man's new environmental tool.

What effect does confrontation with the virtual world have on human behaviour? Is such immersion neutral, or does it influence behaviour or generate different behaviour?

Scientific research was directed towards specific prototypes for learning in a virtual environment with the aim of preparing the user for a new real environment and to encourage his adaptation by devising a new generation of training facilities.

Few multi-disciplinary scientific teams incorporate experimental psychologists, cognitivists and neurophysiologists for studying the perceptive, sensorial and cognitive effects on man in the virtual environment and reflect, *inter alia*, on man's ability to transfer learning from the virtual world to the real world. Such teams are still not very numerous today (Kalawsky, 1999 and Fusch, 1999) in spite of a strongly expressed need to integrate human factor dimensions, both cognitive and sensorial, into technological research.

The development of such collaboration is becoming urgent in the field of man–machine interactions in order to accelerate the development of knowledge and understanding of the virtual reality interfaces which are still limited today. Evaluating the "human factor" component is complex and covers numerous aspects such as performance linked to sensorial capacity and cognitive processes.

It was from this viewpoint, multi-disciplinary team and performance evaluation, that the Human Factors division of ETAS became interested in virtual reality and developed a virtual reality platform with the aim of testing the upper level interfaces in learning specific movements.

4. Experimental Conditions

4.1 Selection of subjects and the experimental task

Experiments were conducted with a group of 27 subjects, all of whom were mine clearance experts. The task was that of target DRI. This simple gestural movement was defined as an activity of blind probing aimed at identifying the structure of a hidden target, using a probe, an intermediate tool extending the operator's hand. The mine clearance expert had to identify three shapes of concealed targets which were rectangular, triangular and round. The mine clearance expert probed into a container placed in front of him, respecting the angle of probing used in mine clearance (between 35 and 45°) and had to identify each shape several times in succession in order to measure the effect of learning.

The mine clearance experts were split into two subgroups one of which had the benefit of a visual aid (a special virtual reality feature which made it possible to show impacts on the target) while the other did not. The chosen variables were the detection time, the number of probings and the quality of the response.

Virtual reality made it possible to display the incidence of the probe with respect to the terrain and to monitor constancy.

4.2 The conditions for exploring the virtual environment

The subject wore a helmet with stereoscopic vision, a V6 from Virtual Research, each channel being connected to a graphic map so that the image was retransmitted in 3D. The mine clearance expert's real probe was used to reproduce direct contact between the hand and the exploration tool. The position of the helmet and the displacement of the probe were controlled (6D) by "flock of birds" position sensors.

The frame of reference was established as a function of the environmental context, which undergoes significant changes in the virtual environment, and the subject's visual capabilities. In order to construct the virtual environment special attention was paid to the selection of the essential markers for forming the frame of reference:

a. at the visual level, according to the concept of identifying the shape and to remain faithful to the analysis of a simple task, the visual markers had basic geometric shapes concealed in an environment with filtered geometrical data and colours. Visual representation of the size of the probe was proportional to its actual size.
b. at the haptic level, according to the concept of transfer of sensorial modalities, the markers were partially transformed into auditory markers. The collision detection points were signalled by sounds which symbolised the times of contact between the probe, the environment and the targets. For gestural

guidance and accuracy reasons, the real medium was replaced by a substitute real homogeneous medium in which the mine clearance expert carried out the probing.

c. at the kinaesthetic level, the constituted virtual environment gave the opportunity of traversing the walls and therefore influenced the kinaesthetic and proprioceptive movement of the subject, who lost the notion of rigidity of the wall.

5. Theoretical Approach

5.1 Sensori-motor and cognitive domain

The observations of this study of a shape detection task were conducted in a sensori-motor learning context. In the real environment, to read spatial information the sensori-motor act is associated with the subject's cognitive capabilities (Paillard, 1985). The treatment of spatial information cross-refers to the detection capabilities and therefore to the attention the subject applies to discriminating sensorial space. This space is a function of the information reflected by the environment. Thus, the sensori-motor act is linked to the attention capabilities of the subject and to the mental loading due to processing the information received from the environment. The subject's performance will also depend on the mental representation of the action undertaken. This information processing occurs in three stages:

- a perceptive stage which corresponds to processing the stimulus;
- a motor stage which is the transmission of the action undertaken on the medium;
- a response processing stage which is the subject's stimulus–response translation.

The identification of an object is the subject of a multi-modal processing (visual, auditory, kinaesthetic and tactile). Similarly, a subject may recode information under several sensorial modalities. However, in order to identify an object each individual will recode according to his particular sensorial predisposition (Ohlmann, 91), which enables the different approaches to be differentiated. Research has emphasised the interactions between the various modalities and the major implications in co-ordinating sensorial activity. Study of the relationship between perceptive systems describes a variation of the predisposition of perceptive systems according to the object of the study (Hatwell, 1994).

The individual mobilises "decoders" as a function of the data to be extracted and of his sensorial capabilities in processing information. Recognition of the shape of an object or stimulus is defined by the object's specific intrinsic characteristics (by its shape, dimensions and colour) and by its extrinsic characteristics (its position and orientation in space).

Given that the visual dimension is predominant in the virtual environment and given that the priority of perceptive systems can change according to the type of task in the real environment, can this perceptive priority be modified in passing from one environment to the other?

How does the individual process information when immersed in a virtual environment? Are the cognitive processes employed in the real world automatically efficient when the person is immersed in virtual reality? The work of Morineau, Boujon, Papin and Le Bouedec (1996) tends to show that the adult plunged into a virtual world for the first time appears to use the cognitive processes coming under the preoperative structures of a 5-year-old infant. These results project the idea that immersion in the virtual world requires acclimatisation or learning.

The cognitive dimensions of the personality may intervene in processing information and have been the subject of numerous papers (Huteau, Marendaz & Ohlmann). In this context the concept of "dependence and independence with regard to the visual field" offers relevant explanations in the real environment.

The DIC (dependence and independence with regard to the visual field) is a theory on the personality factors presented among cognitive styles referring to the work of Witkin (1948). Exploration strategies differ with the IC (independent with regard to the visual field) and DC (dependent with regard to the visual field). Huteau (1985) developed the theory of the DIC and qualifies the IC by higher discriminative capacities and level of vigilance, basing this on egocentric factors and their own perception built on gravitational, proprioceptive or kinaesthetic factors, whereas the DC use more visual factors for referencing themselves in space. They will be very attentive to the positions of others, referring to external factors. Ohlmann and Marendaz (1991) studied this same theory from perceptive conflicts.

Before action, the operator employs a conduct, a manner of proceeding and of giving a reasoning whose degree of complexity varies with the task. In addition to environmental factors, personal factors and the specific nature of the action are going to influence the subject.

The reference point of this study relates to the concept of restricted spaces in a static situation. The subject relies on his capabilities of spatial representation. In order to recognise a shape and characterise it the subject must be capable of selecting stimuli that can be arranged in a simple or complex fashion.

These will be differentiated by combinations of specific information about a shape whose basic identifying markers will be based on arrangements of points characterised by the distance separating them, their orientation, intersection and movement. The subject will mobilise his attention to create grouping factors so as to determine the boundaries and define the contours. In order to perceive a shape and to construct a representation, each subject has need of information which may be total or partial. The person's strategy is based on a representation using part of or all of the constituents of the shape.

Image processing cross-refers to perceptive models of basic features to guide a discriminatory behaviour between global information and more analytical local information. In differential psychology, cognitive styles are evoked by global or analytic strategies in analysing various activities such as learning, memory attentiveness or games strategies.

5.2 A specific feature of the task: remote manipulation

As described above, the mine clearance task is performed blind. The target is masked off from the visual field and probing is carried out with a tool, the probe. The probe is a link enabling three types of sensorial information to be transmitted:

- visual, by the presence of marks left on the surface of the soil enabling the shape to be identified;
- tactile, which makes it possible to detect collisions and identify textures;
- auditory, during collisions for identifying materials.

The problem is to correlate these various sensations.

The mechanoreceptors situated in the hand and at the ends of the fingers possess perceptive acuity which is strongly discriminatory and makes it possible to decode the detailed information which is characteristic of the objects dealt with. Is the acquisition of information as powerful when the hand is not in direct contact with the object?

Recent studies on professional situations where interaction with the world necessitates an intermediary contact object were aimed at measuring the performance of haptic spatial recognition in a real environment (Lederman & Klatzky, 1998). This work was aimed at providing information on tactile manipulation of intermediate interfaces in remote control or in virtual environments.

5.3 The rapid development of the virtual environment

The rapid development of technological and computer facilities over the past few years has resulted in a possible skewing between the initial analyses and recent analyses conducted in virtual environments. The conditions for visual and haptic exploration have advanced and so we can state that the virtual environment is fundamentally different when we experiment with interfaces of different generations. The creation of illusion effects specific to each system makes it possible to assume that the exploratory conditions are not similar and that comparison and transfer of information is difficult.

Applied research conducted on the processing of spatial information in a virtual environment sometimes conveys conflicting data in the learning domain. The exploration conditions cross-refer to two different types of space:

a. large action spaces (representation and orientation)
b. spaces with restricted action (detection and manipulation of simple objects).

This work shows that:

- the choice of reference markers is important for constructing a visual space which becomes the medium for spatial representation for the subject; indeed, a badly monitored activity could affect the subject's representation capabilities;
- the performance is sensitive to spatial distortion, restriction of the visual field and to the effects of depth.

The perceptive conflicts between movement and vision hamper the precision of the gesture and may modify the speed of movement of the gesture (Coello, Decety, Leifflen & Orliaguet, 1996) and, because of this, the concept of learning transfer between a virtual and a real world is compromised. On the other hand, the individual may acquire a performance on a particular sensorial capability.

The integrity of cross-reference in the virtual environment is an important factor. Is the perception of information received in a real environment faithful to the perception of information received in a virtual world? This concept of environmental fidelity involves the psychological judgement of the subjects plus the technological concept.

A virtual environment which makes it possible to lift the mask over the hidden task offers the subject the opportunity of memorising more complete information and enriching his spatial representation by the effects of 2D and/or 3D visualisation and of "rejects"; the hypothesis that the subject is able to transfer this information by limiting the affects of spatial knowledge may then be raised.

The virtual environment makes it possible to substitute one sensorial factor for another on the concept of amodality and in this way to isolate a sensorial process in order to obtain a better understanding of it. These artefacts can also make it possible to limit the mental load on the subject facing a heavy use of the equipment.

There are numerous controversies on:

- whether there is a need to reproduce identically the needs felt in a real environment for a simulation tool when there is a risk of its resulting in a heavy mental loading on the subject;
- the employment of cognitive capabilities in co-ordinating information from visual space and motor space in the virtual environment;
- the development over time of processes used in virtual environments;
- the need for modulation for subjects' interpersonal dimensions during information processing in virtual reality.

6. The Results of Experiments in Compared Environments

The objective of the thesis was to compare conditions for exploring a shape under real and virtual environments using simple interfaces for assessing subjects' performance on the acquisition of spatial information.

6.1 The needs of subjects in the real environment

The three shapes proposed require the operator to make a double category recognition: object is round or angular; if angular decide the aperture angle. These are exocentric factors that the subject will seek to identify in order to

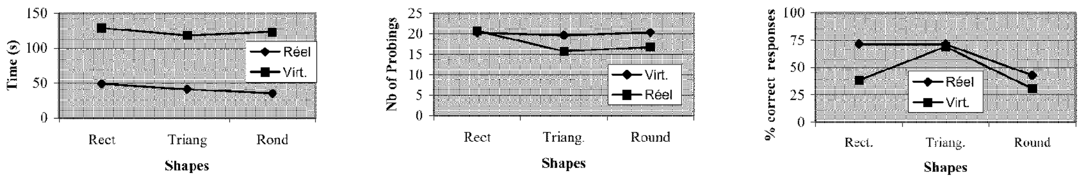
differentiate the three shapes. This observation has facilitated the breakdown of the gestures into these different translational and rotational movements.
We then observe that, in order to detect a shape:

- performance is not linked to expertise, which enables us to formulate the hypothesis that the subjects' personal strategies would have a discriminatory nature independent of the training received;
- the subjects' performance varies as a function of the simple shapes to be identified;
- the subjects' performance varies as a function of the environments concealing the shapes;
- processing the information for detecting a shape and its texture could be first class in the various uni-sensorial or bi-sensorial modalities while revealing a graduation in performance measurement;
- the cognitive style of dependence and independence with regard to the visual field is insufficient to explain the subject's strategy when he is referring mainly to the visual field;
- individuals have identification strategies for breaking down a shape according to the shape strategy concepts.

6.2 Comparison of learning in real and virtual environments when making a detailed gestural manipulation remotely

The results were obtained from variance analyses in order to measure four main effects which were: the environmental condition; learning; visual modality; and interpersonal variability.

6.2.1 The effect of the environmental condition enabled us to distinguish between real and virtual performance



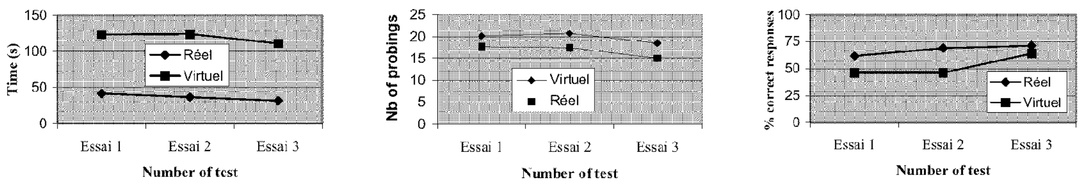
a: Probing time **b:** Number of probings **c:** Percentage of correct responses

Figure 1: Probing times, number of probings and percentage of correct responses of shapes for 1 test as a function of environment conditions.

The detection of a shape in the virtual environment required three times as long as in the real environment. The average time in the real environment was 42 s whereas it was 123 s in the virtual environment. Whereas the number of probings remained similar, the mean deviation between the two situations was three points. In contrast, the quality of the responses varied between the two situations. In the real environment we had 62% correct responses whereas in the virtual environment we obtained 46% correct responses (average for the different shapes).
The shape influences the subject's performance. The triangle, with a quick detection time, had the best success percentage in both conditions. The rectangle and the round shape showed detection conditions were more difficult, increasingly so in the virtual environment both for time and for correctness of response (Figure 1).
In order to determine a geometric shape the probing time increased considerably in the virtual environment, but, however, without, the action undertaken by the subject being changed significantly, and without this increase in time affecting the quality of the response. Although there was no increase in motor activity (that is in the number of probings), we did note that the time spent on concentration, attention or reflection was longer for an achievement of detection capability which was less difficult than one in a real environment. Although the subjects spent far more time to achieve an identical result, we can reckon that this difference in time is marked by the modification of sensori-motor activity and/or cognitive activity in order to compensate for the search for new identifying markers.

6.2.2 The learning effect

Learning was measured by systematic repetition of three tests for all subjects. This enabled us to eliminate the effect of chance.
Here, we found that the deviations in detection time between the first and third test were significant (Figure 2). For the first test we recorded 123s and for the third, 111 s. Differentiating the two environments we observe that the time curves decrease in parallel with the tests (Figure 1).
In terms of the quality of the response, the percentages increased during the three tests. They varied from 54.5% in test 1 to 66% in test 3, and the percentage of correct responses in the virtual environment showed a greater increase between test 2 and test 3.
Once again, for the number of probings we identified a slight deviation between test 1 (17.5%) and test 3 (15.5) which is not significant. Repeating the tests made it possible to commence learning under both environmental conditions (Figure 3).



a: Detection time **b:** Number of probings **c:** Percentage of correct responses

Figure 2: Detection times, number of probings and percentage of correct responses of shapes for the three tests in real and virtual environments.

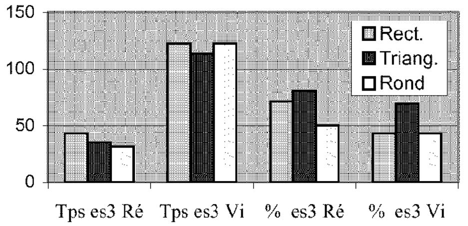


Figure 3: In the learning situation, comparison of time and % of correct responses for shapes between real (Re) and virtual (Vi) for test 3 (T3).

This learning is identified in real and virtual environments. Although the changes in time and number of probings are small we observe there is a marked increase in the percentage success. The display of the third test results also shows disparities in the detection of shapes.

6.2.3 The effect of visual modality in the learning situation

The contribution from this visual modality is measured on a special aid provided by the virtual environment. After each test, half of the subjects received a display of the probing points that they were able to superimpose over the shapes sought.

The sub-group benefiting from the visual aid detected shapes more quickly (99 s) than the sub-group without the aid (119 s), still with a deviation of 3 points on the number of probings. In contrast, with quicker detection the subjects using the aid answered with 70% correct responses whereas the sub-group without the visual aid had only 50% correct responses.

The presentation of visual information was envisaged as an aid to detection. This visual window offered space for reflection, allowing the subject to readjust the processing of the information obtained blind in order to confirm or reject the shape detection decision.

It appears that the subject reinforces his action at each new test in the virtual environment by still mobilising his sensori-motor activity just as much. In contrast, we found a slight reduction in the time, in parallel with an increase in the quality of the responses. The visual aid became an aid for representing the shape. It caused reflection on the action and enabled the subject to readjust his strategy for the next test.

6.2.4 The personal effect

This effect was measured initially after the subjects were divided into 4 sub-groups in accordance with the GEFT (group embedded figures test) which is a perceptive test measuring the capability of subjects to extract a simple shape from a complex figure.

On a test and per sub-group, the average detection times ranged from 68.62s to 112.36s for the number of probings from 50.5 to 82, and for percentages of correct responses from 47.5 to 80.

The variation in data between sub-groups did not correspond to the results expected. The performance specified by sub-group 1, identified as dependent with regard to the field, distinguished processing strategies defined in reference to Huteau's concept. In contrast, sub-group 4, categorised as independent with regard to the field, represented an "economic" processing strategy for the three variables: time; number of probings; and percentage success. These data are currently being studied to break down the perception strategies.

7. Subjects' Perception of the Virtual Environment: Review of Conversations

Subjects' conversations during the experiments provided us with the following information.

7.1 Visual perception of the context

The visual perception of an object in our case revealed a dispersion on the size of the object which was assessed at between 5 and 30 centimetres (the true dimensions being 15×15). Evaluation of the size of an object in a virtual environment was often unrealistic and varied from person to person with some over- or under-estimating, but others correctly assessing the dimensions of the target.

The visual perceptive conflict is the search for a visual compromise between the intention of accurately aiming a probing point and the possibility of reaching this precise probing point. In the present case, the subjects had to seek to align several probing points in order to create visual markers of the shape and to trace a curve, a straight line or an angle.

All subjects mentioned visual fatigue after the repetition of three tests interspersed by returns to a real environment. It was for this reason that we limited the learning to three tests.

7.2 Sensori-motor perception of the context

The time taken to perform a task under motor control.

The relationship of speed/accuracy of arm and hand movements, measured by the time between picking up the probe in the hand and identifying the target, was clearly modified in the virtual environment. For the detailed and precise gestural movements of the mine clearance expert, the subject will have to slow down his movement by continual monitoring in order to adjust his gesture. This means that the subject is going to have to adapt his sensori-motor movement by developing a slower gestural movement in order to achieve success or otherwise of the task undertaken.

The lack of sensori-motor and haptic information.

The virtual presentation of the target (visual and auditory factors) lacks haptic information, located mainly on the edges of the target. The need for this is revealed in the mine clearance expert's gestures by the manner of proceeding to obtain accuracy for the angular or rounded criterion.

8. Conclusion

For this paper, comparisons of conduct and learning in two environments enable us to report that the performance acquired when making precise gestural movements in a virtual environment is lower than the performance achieved in a real environment. However, we can state that repeating the tests enhances the speed/accuracy factor. The improvement seen in the two situations demonstrates that the subjects adapt and develop with this new environment. One advantage of the virtual environment in learning compared with the real environment is that it offers the possibility of calibrating the task on one or more modalities in order to measure the significant individual and collective performance on simple tasks. It could become a simulation tool of benefit to mankind, offering the possibility of isolating or combining several types of information in order to verify the specific needs of the individual.

9. Development

The results of this study have enabled us to specify the changes to the virtual environment needed for the mine clearance expert's DRI task. The new application uses:

- a Proview 60 helmet which, combined with a more powerful machine and graphics cards, has made it possible to improve the visual aspect and to stabilise the image;
- modelling of two real mines;
- a Phantom 1.5 3DoF force feedback arm which makes it possible to provide haptic effects (especially when detecting collisions), a more precise manipulation of the probe position (which enables the detail of gestural movement to be increased).

For budgetary reasons when specifying these changes, the force feedback was limited to translational movements. While it is necessary, theoretically, to constrain the probe to 5 degrees of freedom (3 translations and 2 rotations — pitch and yaw) for guiding the probe over the ground, this is not possible with the 1.5 3DoF version of the Phantom. In the absence of guidance, the displacement of the point of intersection of probe with the surface of the terrain, due to lack of gestural accuracy, is visualised in the virtual world and leads to a perceptive conflict.

In order to overcome this technology limitation, as soon as the end of the probe contacts the ground it is subject to guidance by a point within a tube along the probe axis of incidence, and the image of the probe is locked to this axis.

This artefact serves as a decoy for the operator's sense which, when the probe is free to move in rotation, works along a single translational axis.

In version 2 (addition of force feedback) this demonstrator could become a genuine tool for learning mine clearance strategy, enabling the instructor to validate the relevance of probings (searching for limits, width and height, detecting contours, enabling the shape to be identified), minimising the number of probings by developing strategies depending on the sensorial data received and thereby increasing the reliability of decisions in a real operation. In time, this tool could also make it possible to teach the technique to civilian populations and thus accelerate the decontamination process which is still long, costly in terms of money and also of human life.

Technology development already permits us to envisage version 3, a portable system which, by mathematical analysis of the probing geometry and comparison with a mine database, can offer a genuinely improved aid to decision making and processing in real operations. The greatest problem is to obtain a system which is not liable to trigger the mine irrespective of the latter's technology and therefore this means a system which does not emit a signal or signature of any kind.

With sociological problems overcome, we can envisage using a master force feedback arm to remotely operate a slave arm fitted with a probe; while retaining the skill aspect of the sapper's job, it would then become possible to shift the task towards the rear and thereby make mine clearance operations safer.

It nevertheless remains true that, beyond technology, the best way of obtaining terrain completely free from the presence of mines is not to mine it in the first place.

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